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Takayasu et al.

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(45) Date of Patent: Oct. 29, 2024

(54) **SOUND EMITTING APPARATUS**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**

H04R 17/00 (2006.01)
H04R 1/02 (2006.01)
H04R 1/28 (2006.01)

(52) **U.S. Cl.**

CPC ***H04R 17/00*** (2013.01); ***H04R 1/025*** (2013.01); ***H04R 1/2811*** (2013.01); *H04R 2400/11* (2013.01)

(58) **Field of Classification Search**

CPC H04R 17/00; H04R 1/025; H04R 1/2811; H04R 2400/11; H04R 17/10
See application file for complete search history.

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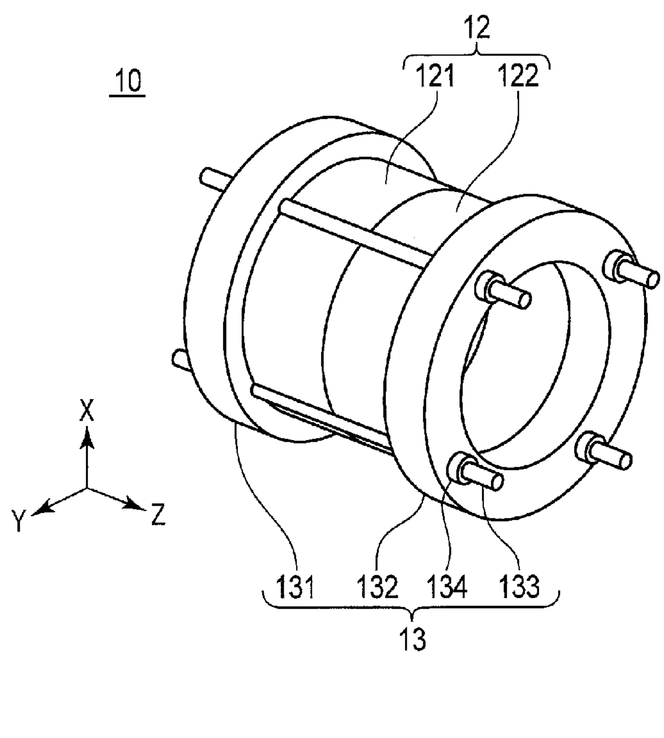
Primary Examiner — Oyesola C Ojo
(74) *Attorney, Agent, or Firm* — Oblon, McClelland, Maier & Neustadt, L.L.P.

(57) **ABSTRACT**

According to an embodiment, a sound emitting apparatus includes a vibrator, a holding part, and a fixing part. The holding part is configured to hold the vibrator. The fixing part is configured to fix the holding part. A stiffness of the fixing part is lower than a stiffness of the holding part.

20 Claims, 19 Drawing Sheets



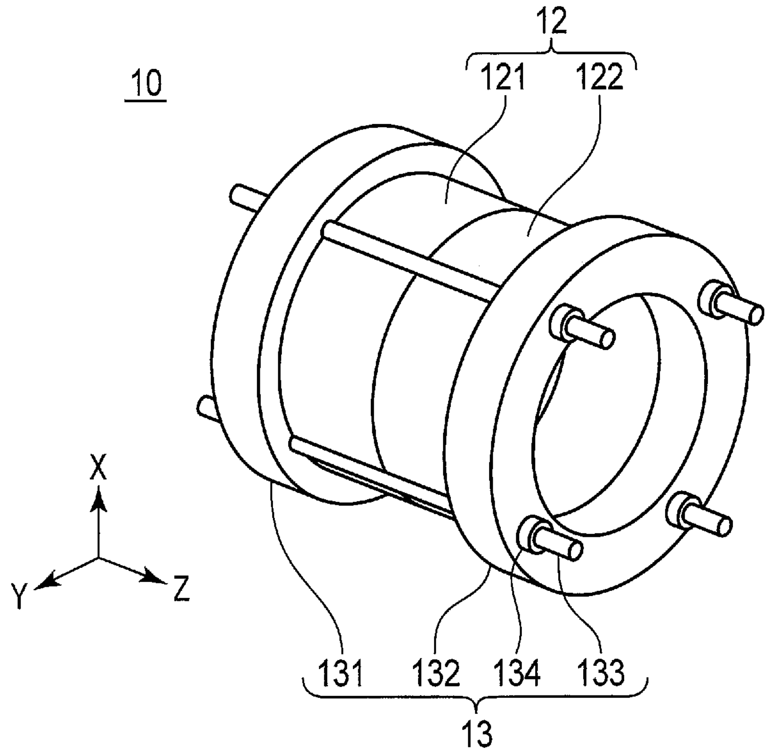

10
12
121
122
X
Y
Z
131
132
134
133
13

FIG. 1

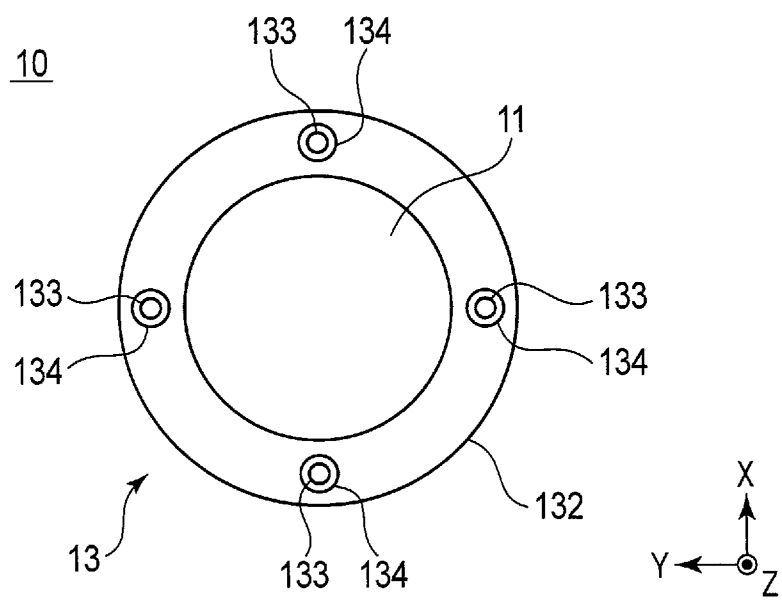

10
133
134
11
133
134
133
134
13
132
133
134
X
Y
Z

FIG. 2

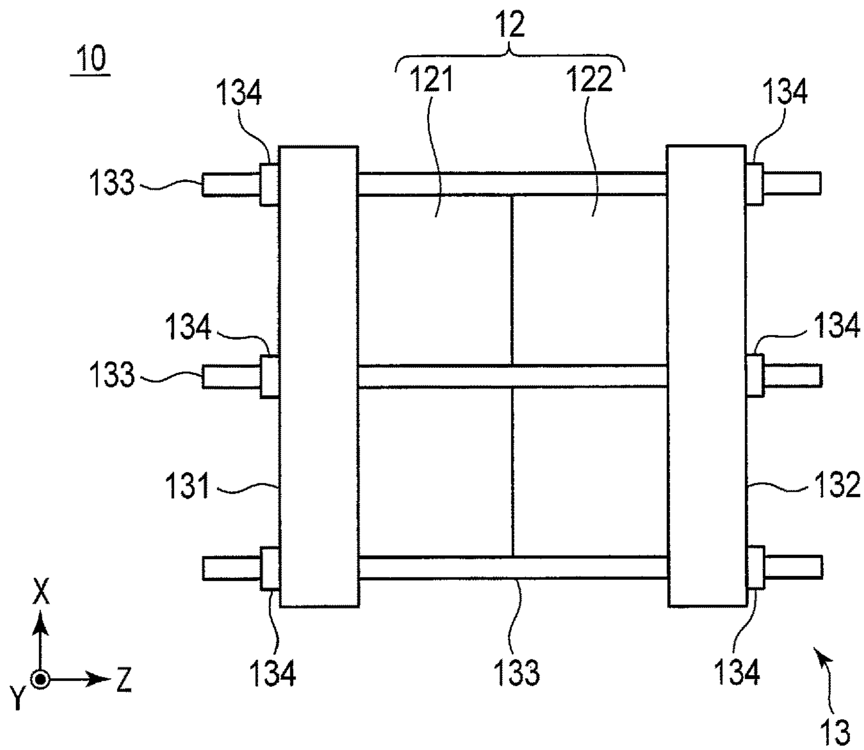

10
12
121
122
134
133
134
133
131
132
134
133
134
13
X
Y
Z

FIG. 3

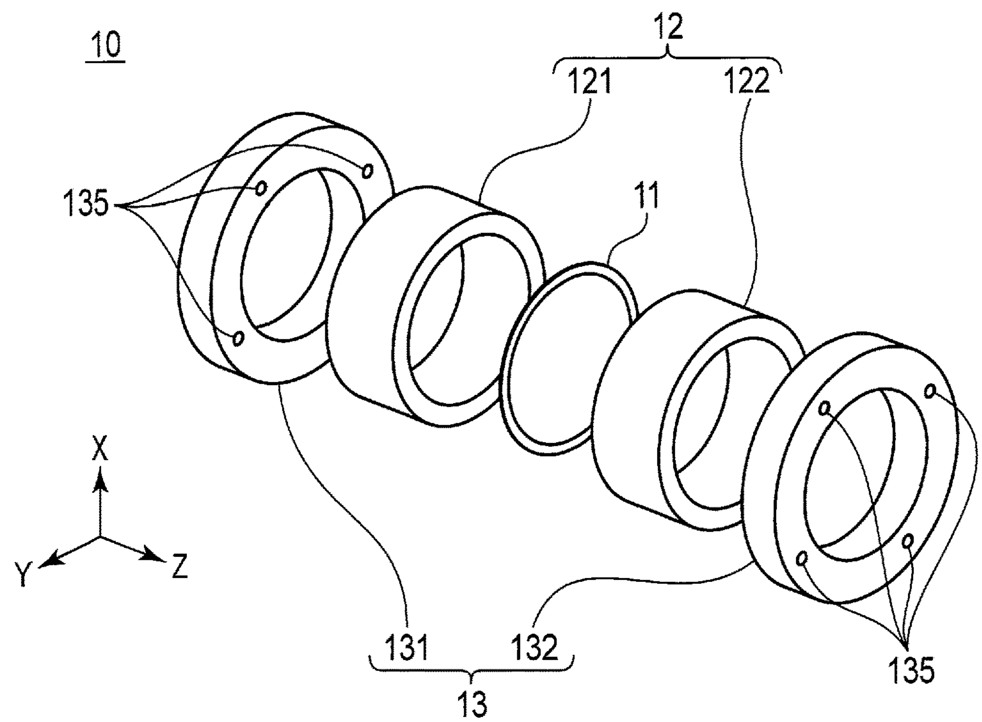
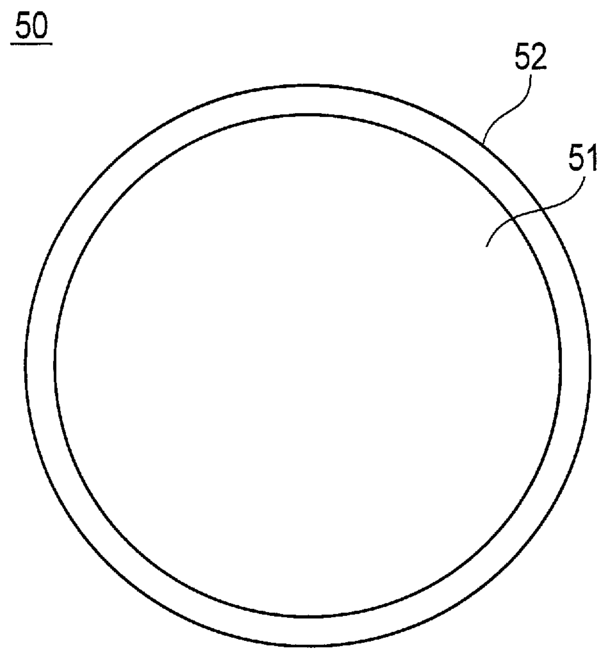
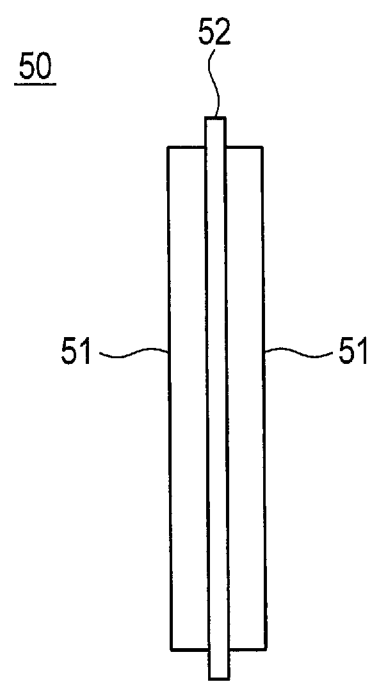

10
12
121
122
135
11
X
Y
Z
131
132
13
135

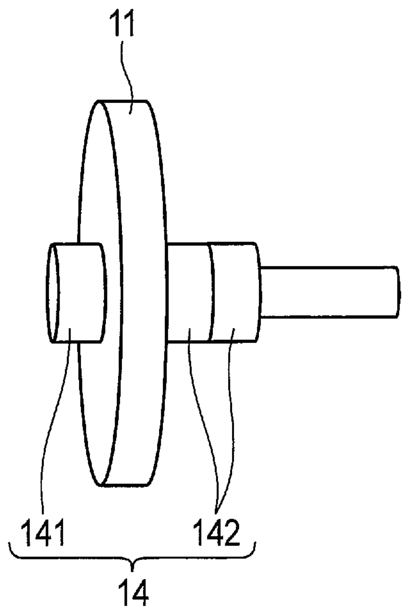
FIG. 4



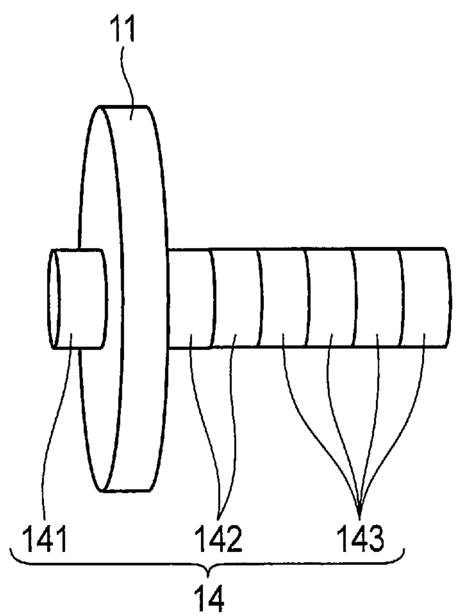
F I G. 5A



F I G. 5B



F I G. 6



F I G. 7

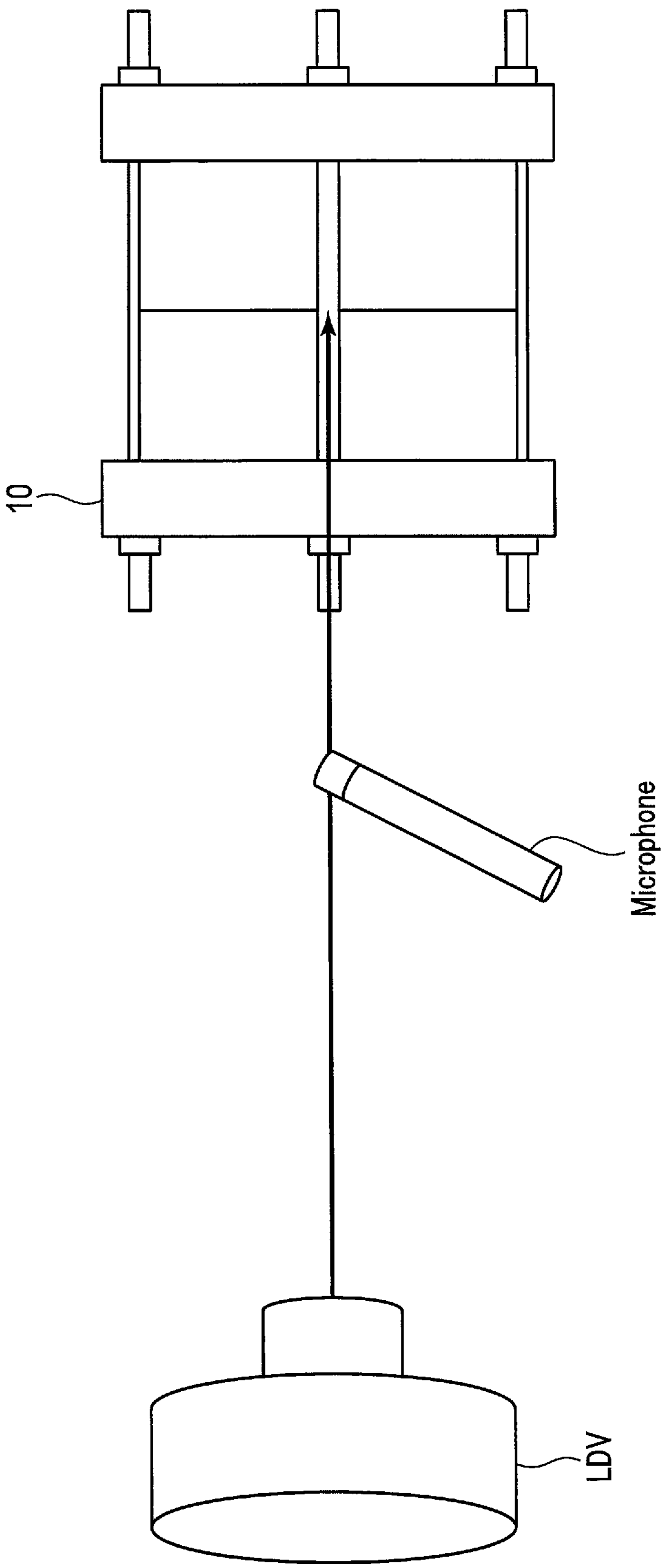
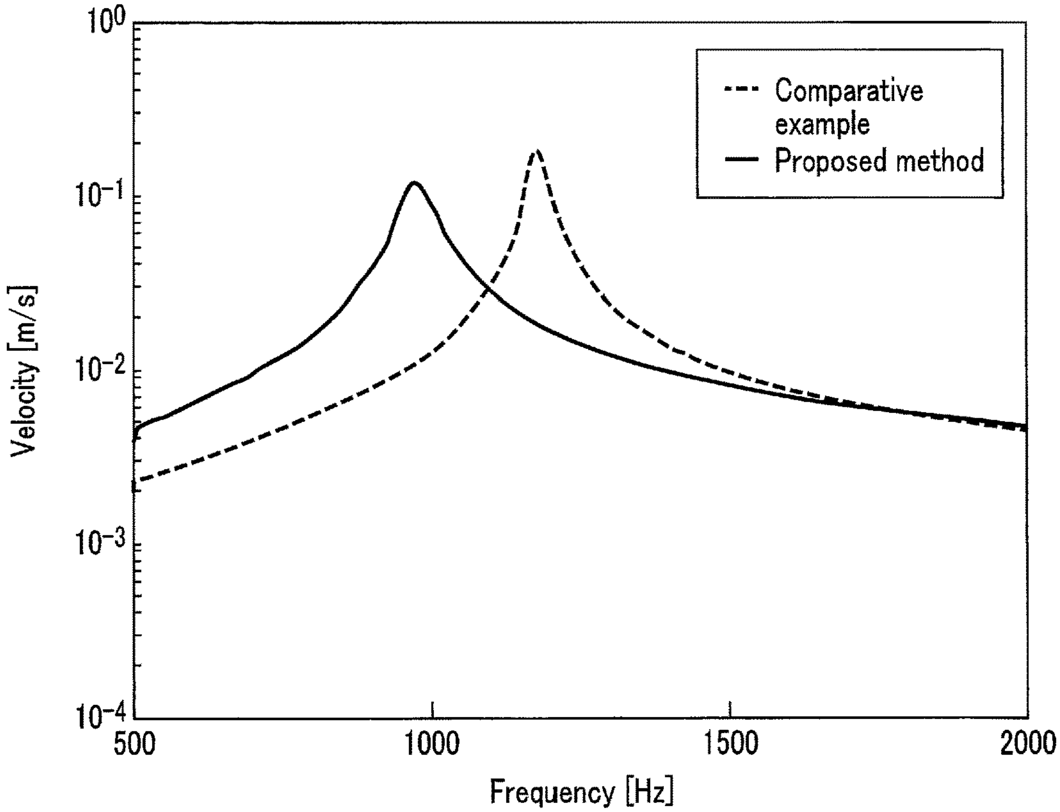
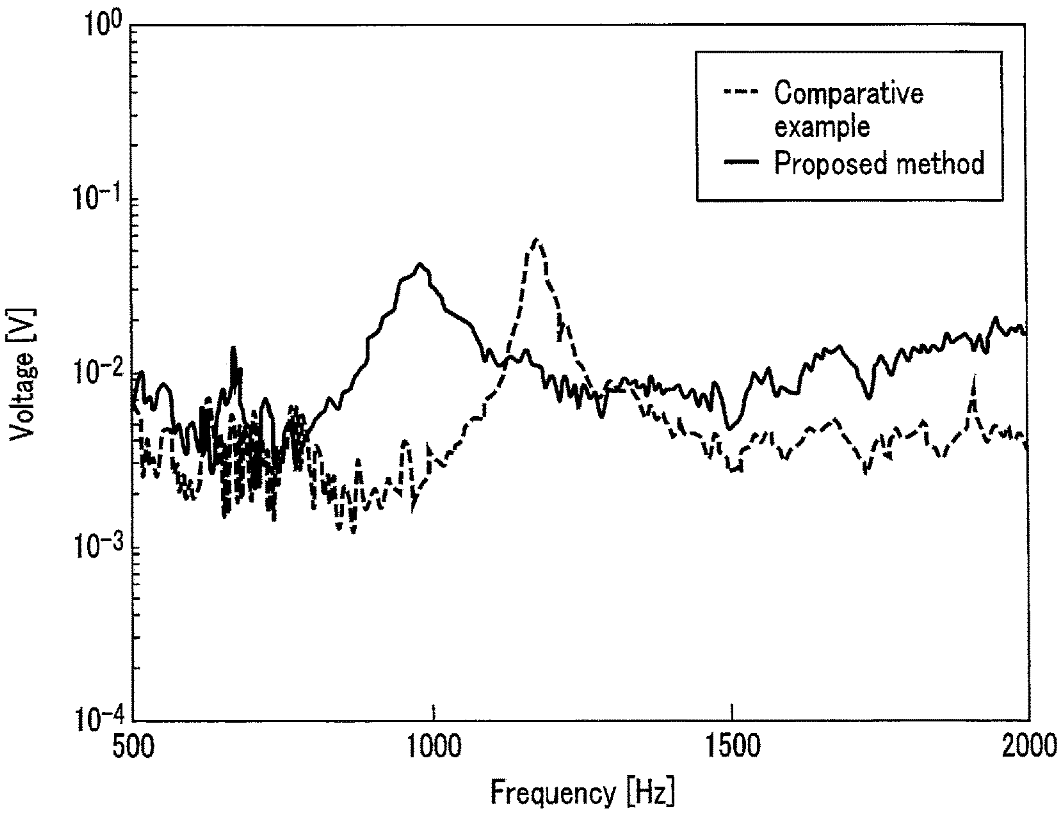


FIG. 8



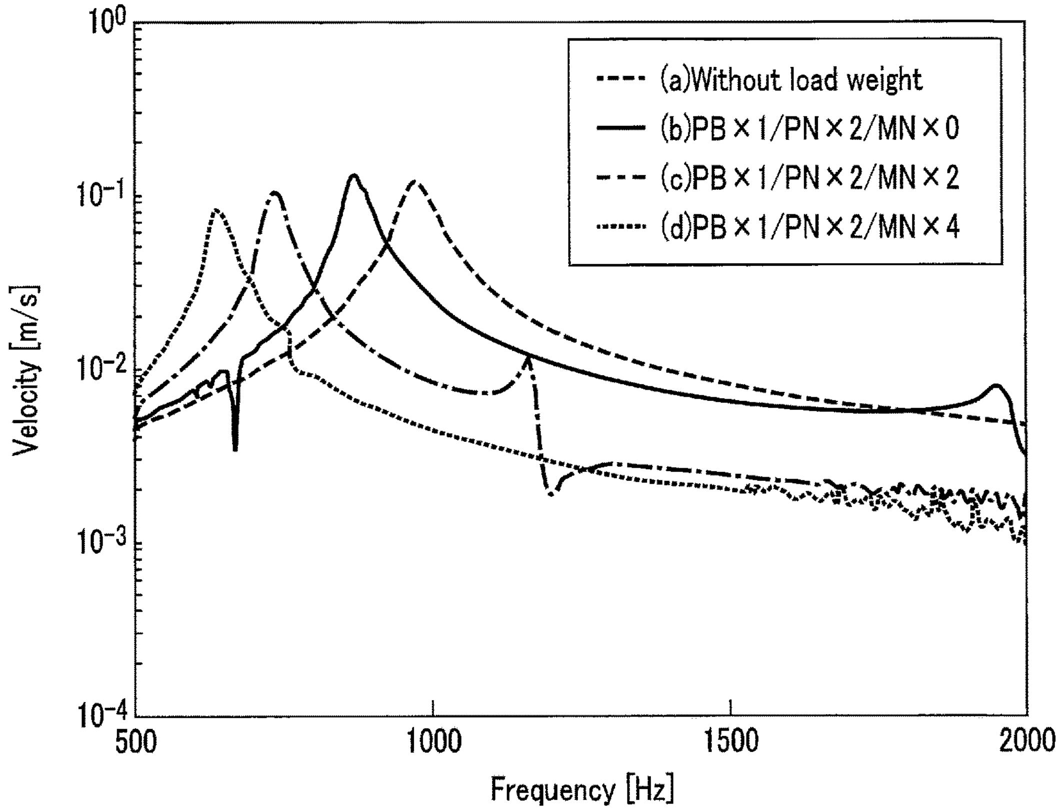
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Velocity [m/s]
500
1000
1500
2000
Frequency [Hz]
Comparative example
Proposed method

FIG. 9



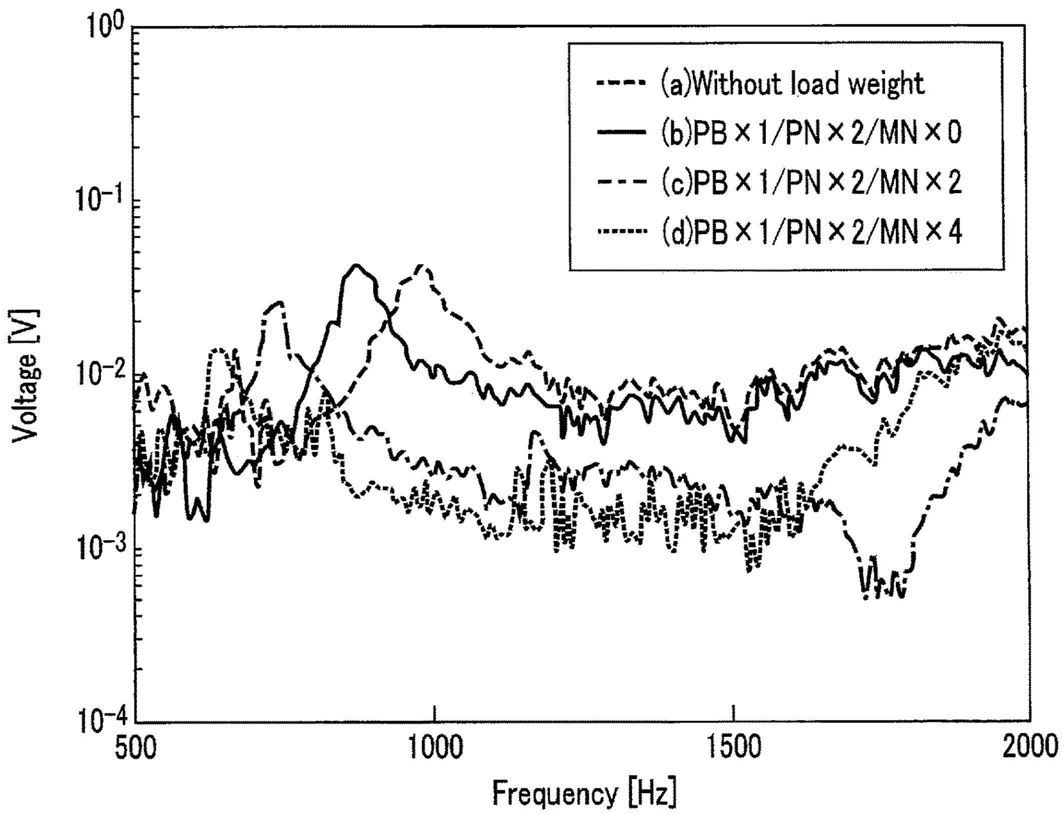
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
Voltage [V]
500
1000
1500
2000
Frequency [Hz]
Comparative example
Proposed method

FIG. 10



(a)Without load weight
(b)PB×1/PN×2/MN×0
(c)PB×1/PN×2/MN×2
(d)PB×1/PN×2/MN×4
Velocity [m/s]
Frequency [Hz]

F I G. 11



(a)Without load weight
(b)PB×1/PN×2/MN×0
(c)PB×1/PN×2/MN×2
(d)PB×1/PN×2/MN×4
Voltage [V]
Frequency [Hz]

F I G. 12

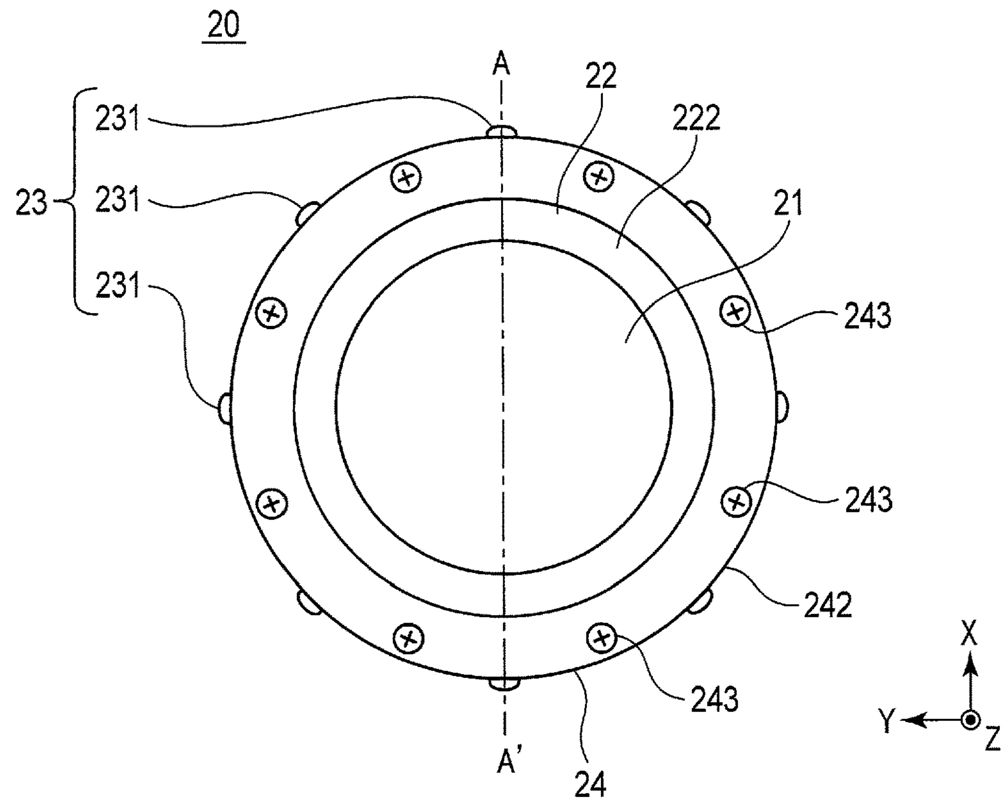

20
A
22
222
21
23
231
231
231
243
243
242
243
24
A'
X
Y
Z

FIG. 13

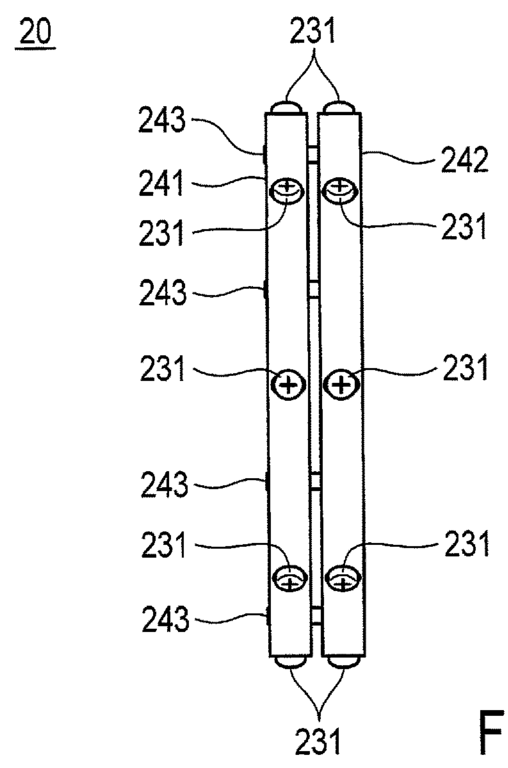

20
231
243
241
231
243
231
243
231
243
242
231
231
231
231

FIG. 14

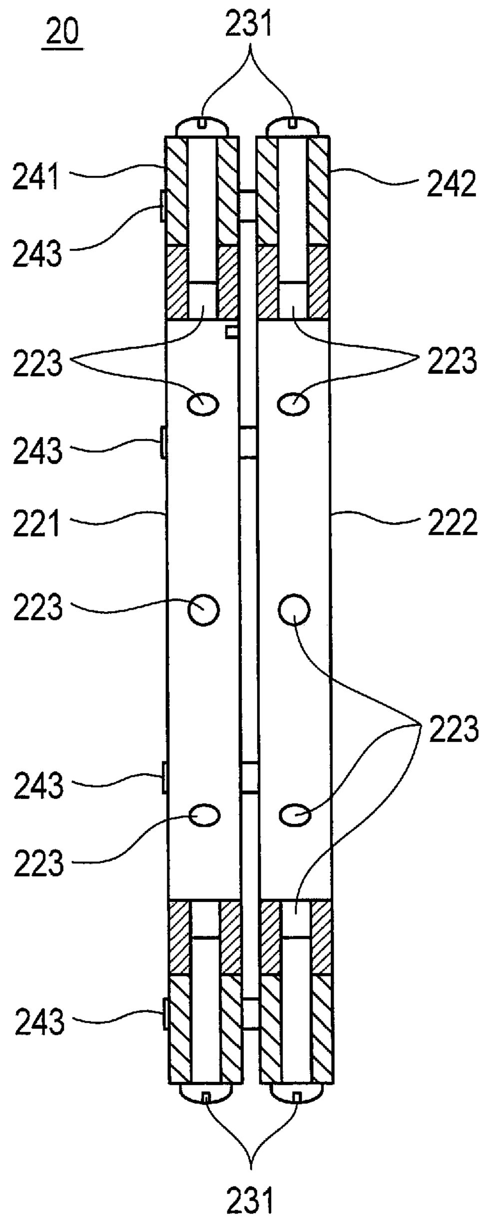
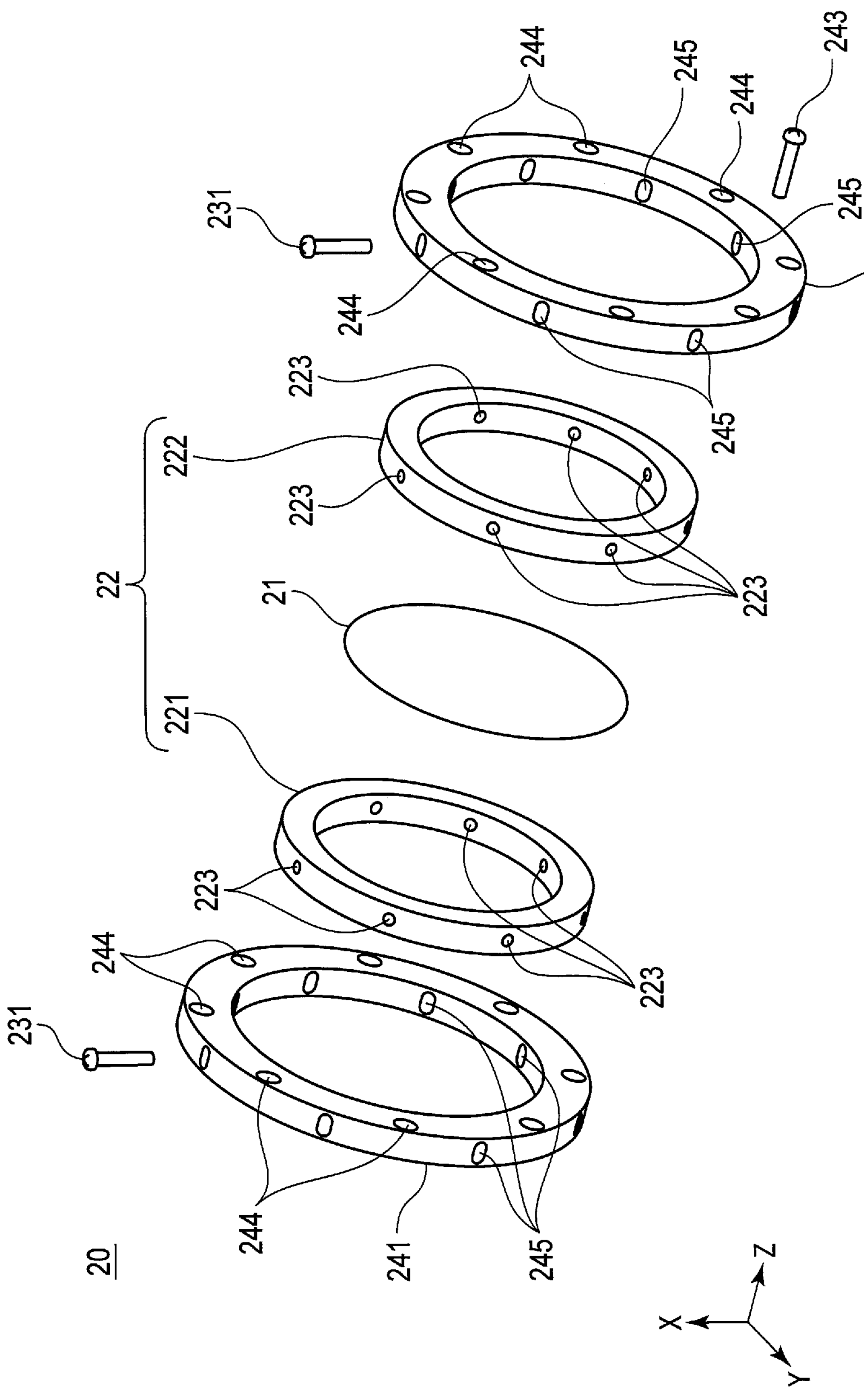
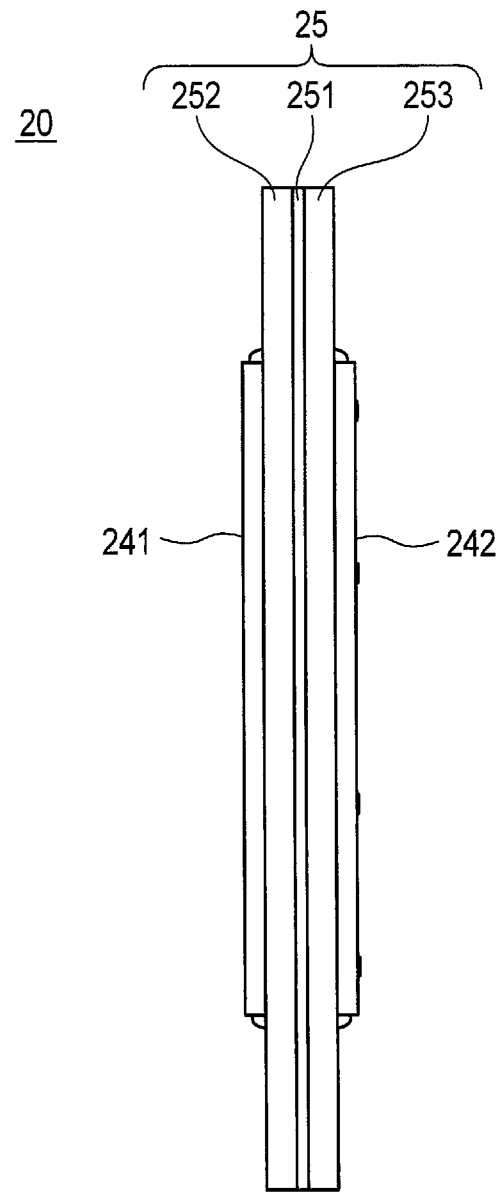


FIG. 15



F I G. 16



F I G. 17

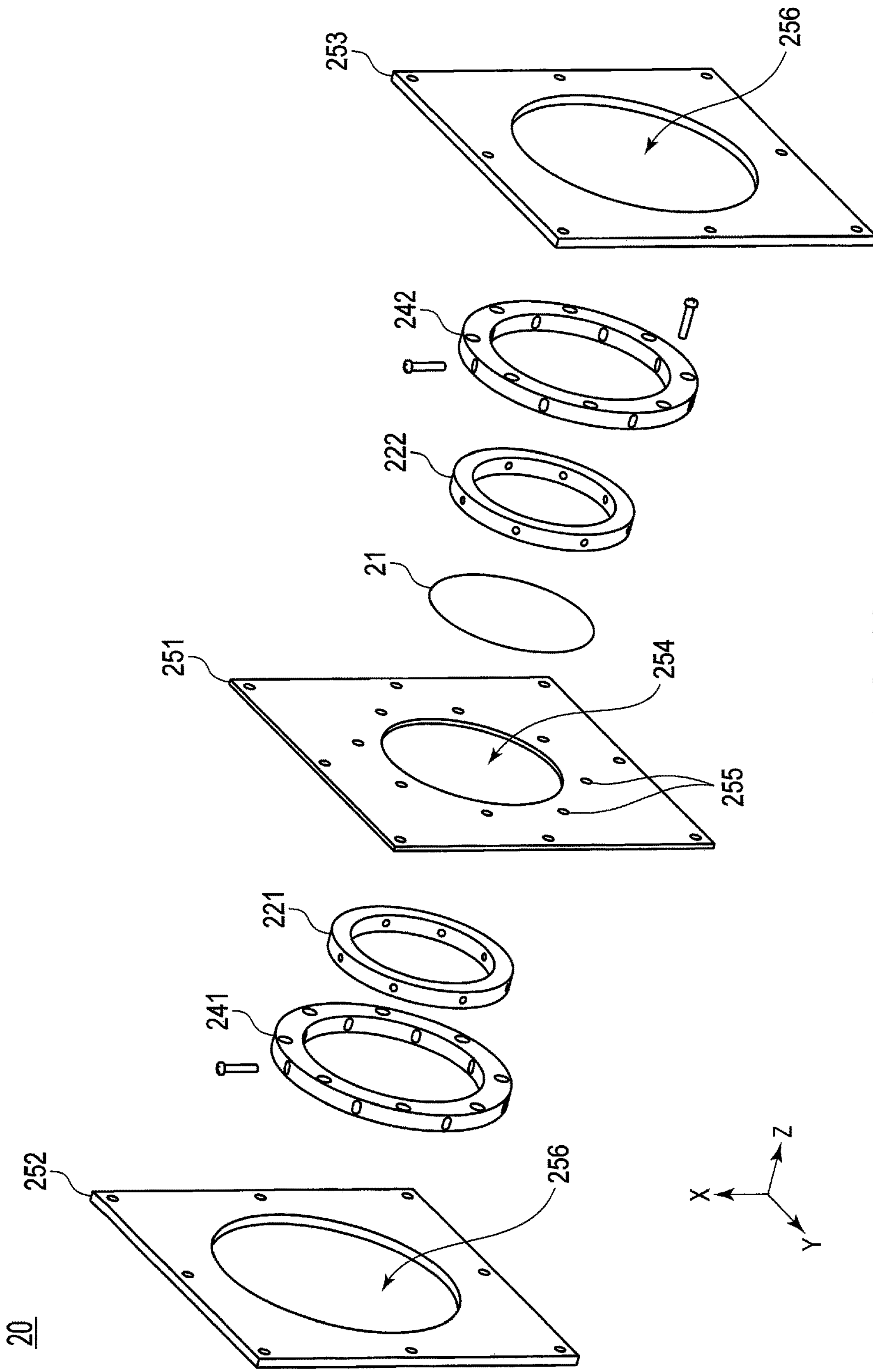


FIG. 18

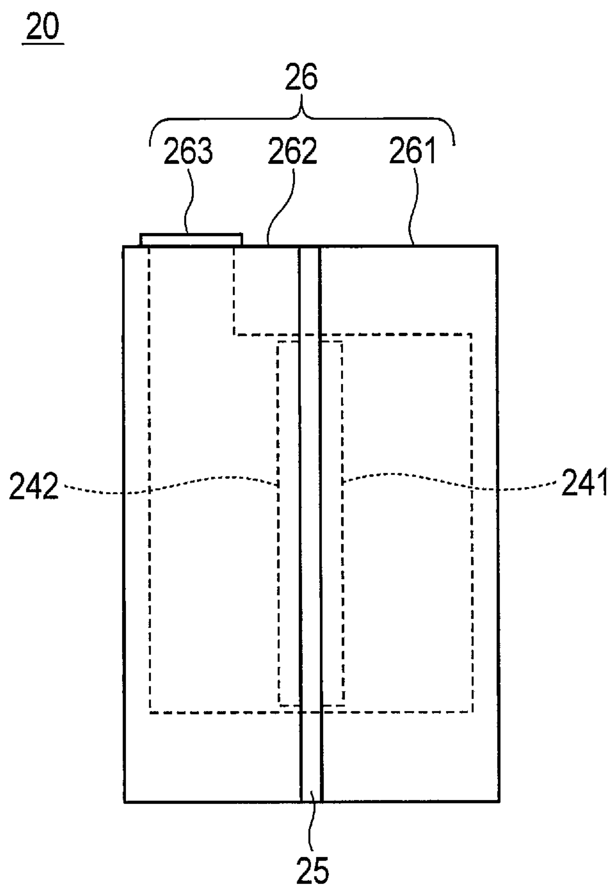


FIG. 19

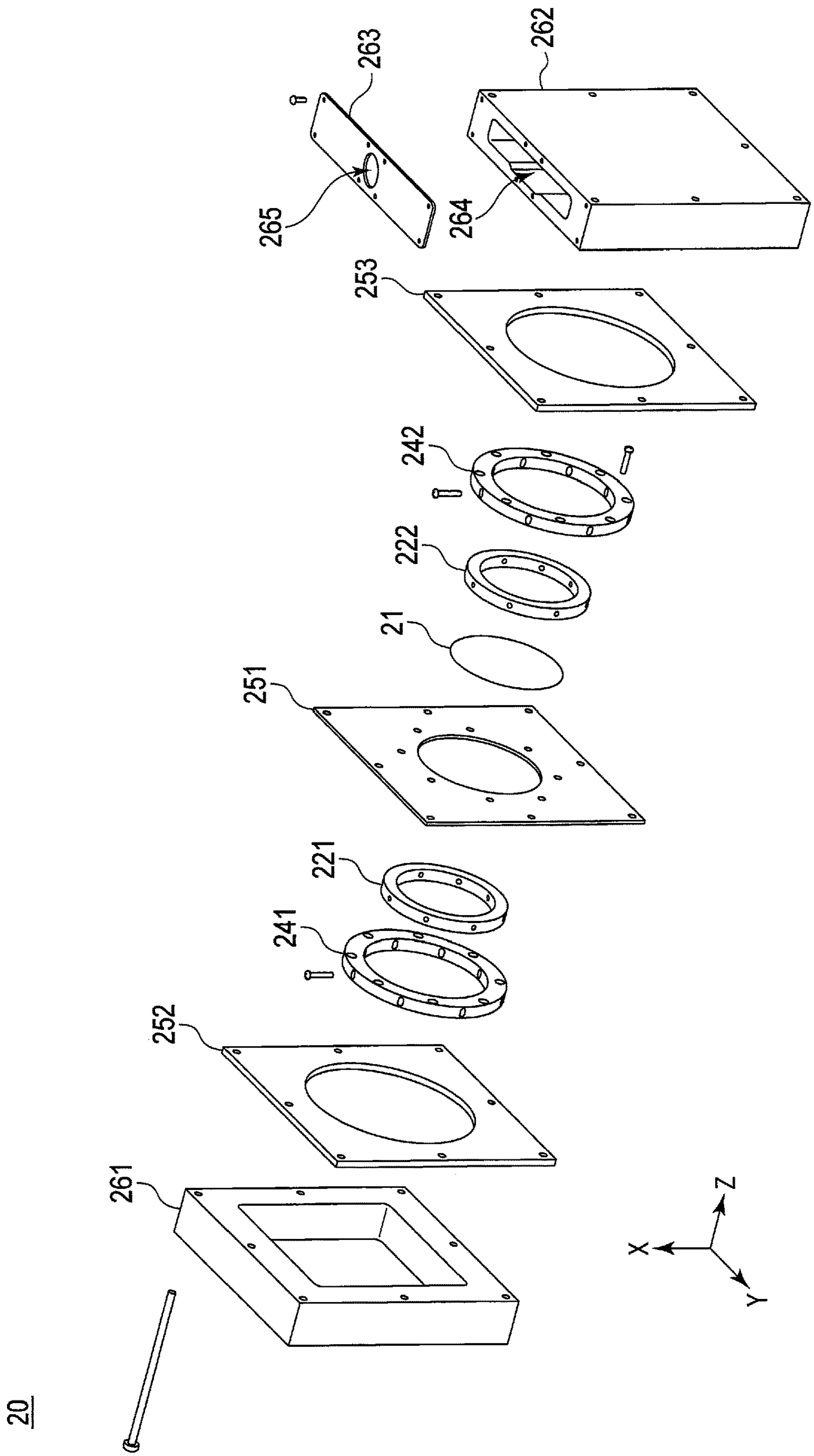
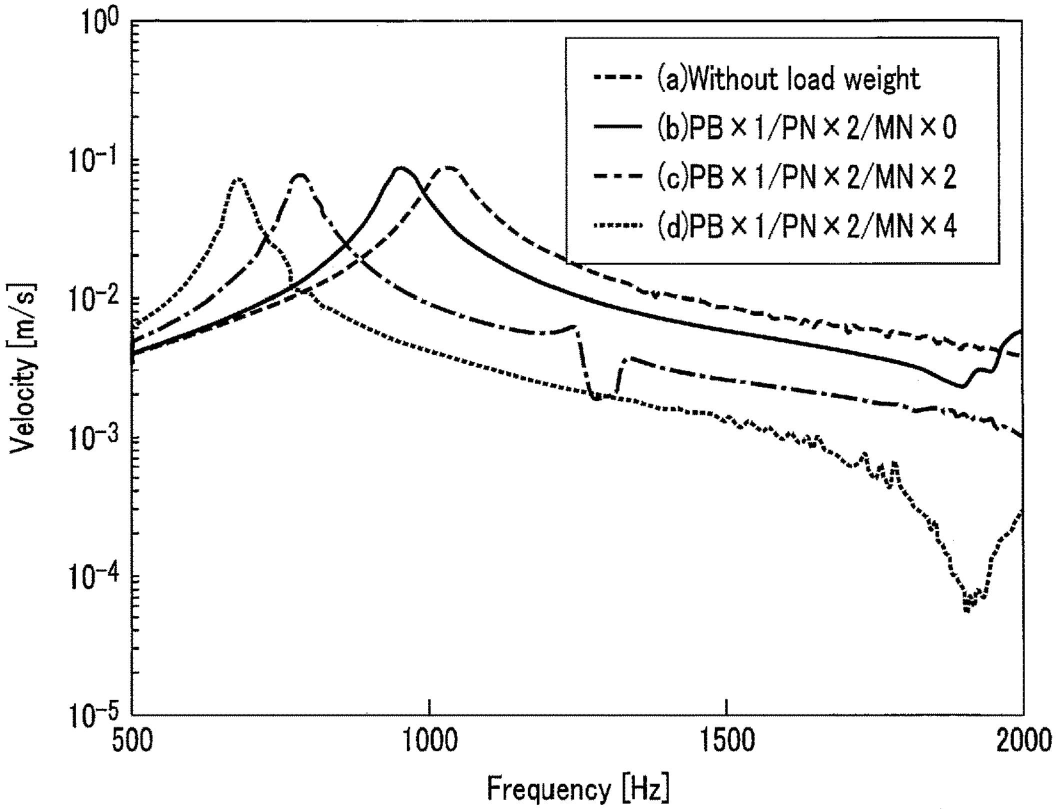
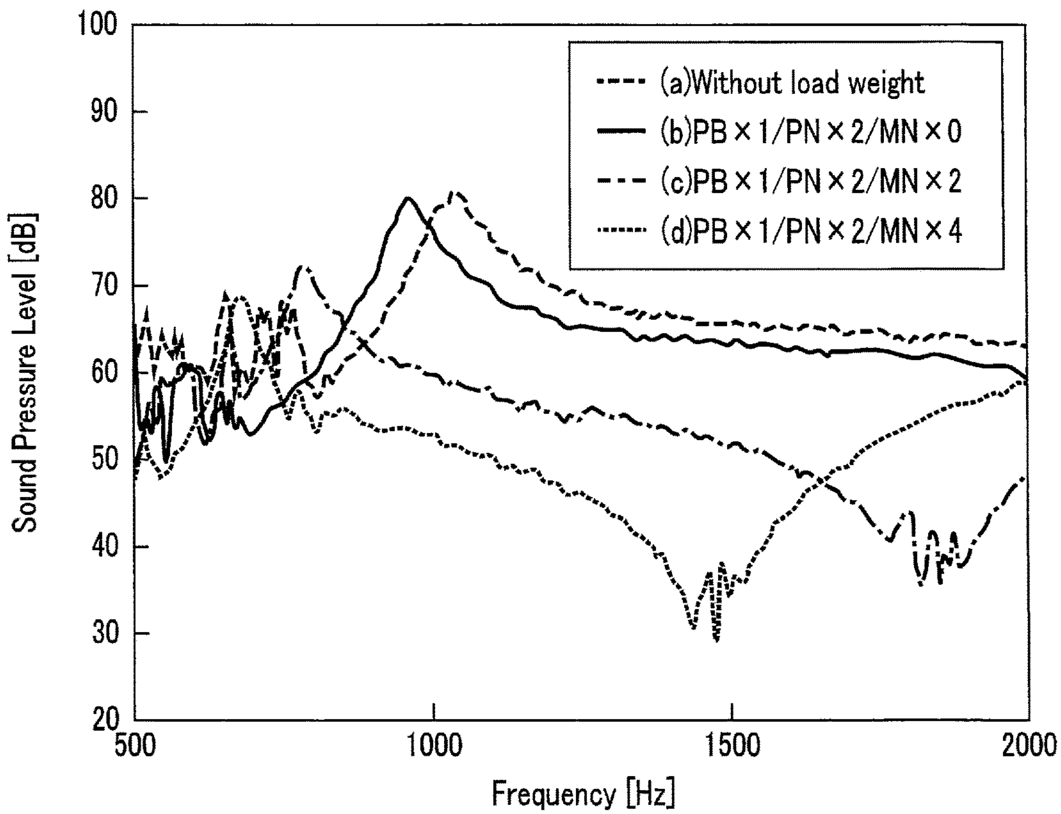


FIG. 20



(a)Without load weight
(b)PB × 1/PN × 2/MN × 0
(c)PB × 1/PN × 2/MN × 2
(d)PB × 1/PN × 2/MN × 4
Velocity [m/s]
Frequency [Hz]

FIG. 21



(a)Without load weight
(b)PB × 1/PN × 2/MN × 0
(c)PB × 1/PN × 2/MN × 2
(d)PB × 1/PN × 2/MN × 4
Sound Pressure Level [dB]
Frequency [Hz]

FIG. 22

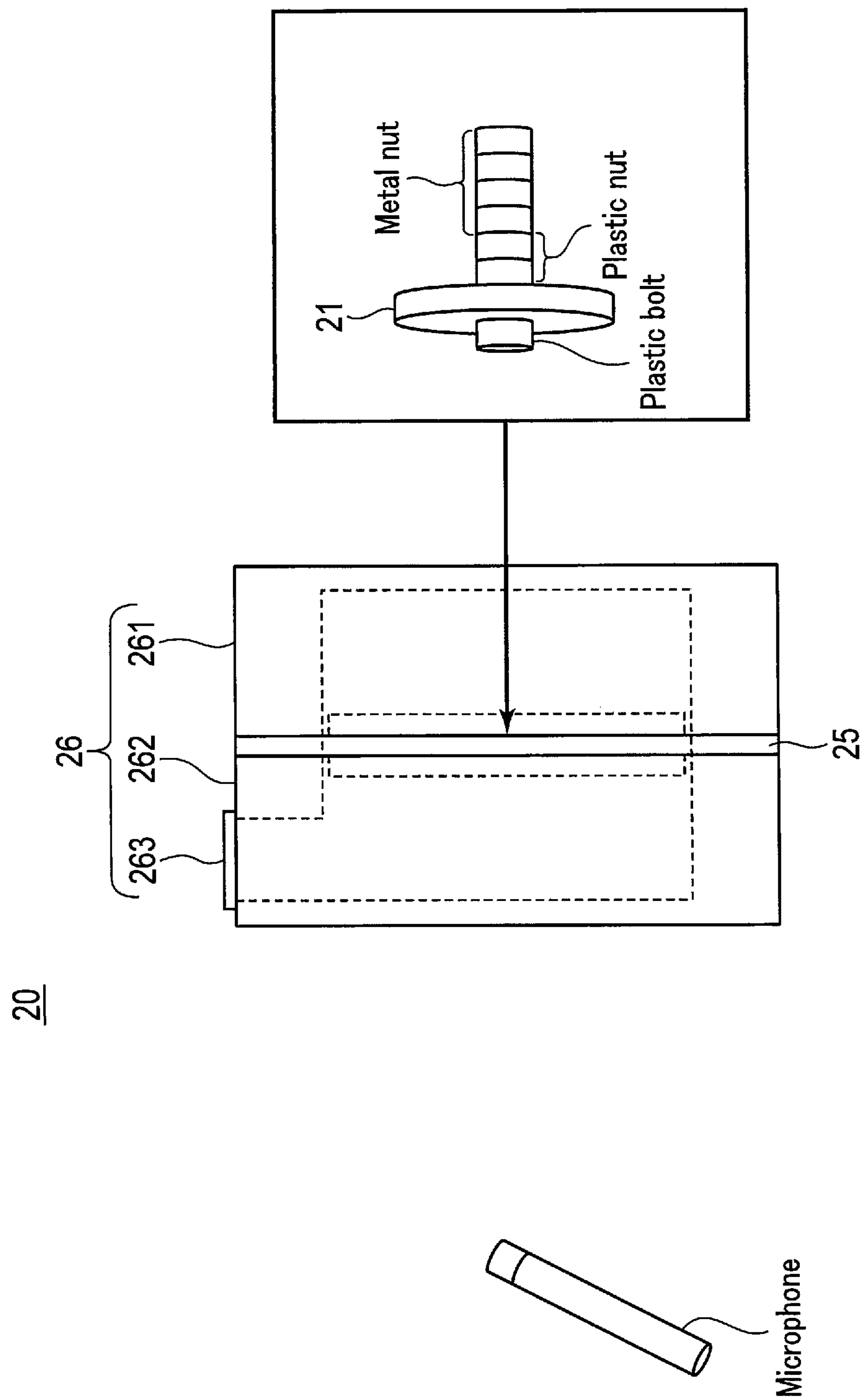

Metal nut
Plastic nut
21
Plastic bolt
26
261
262
263
25
20
Microphone

FIG. 23

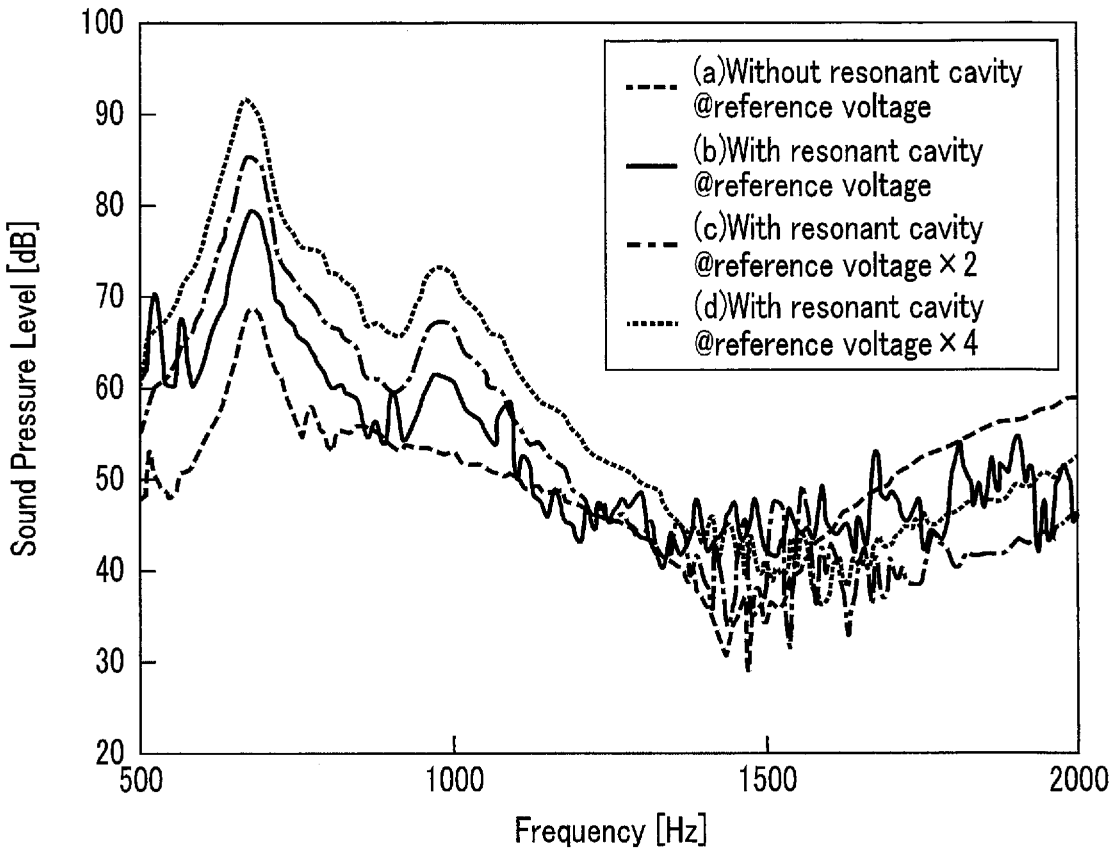
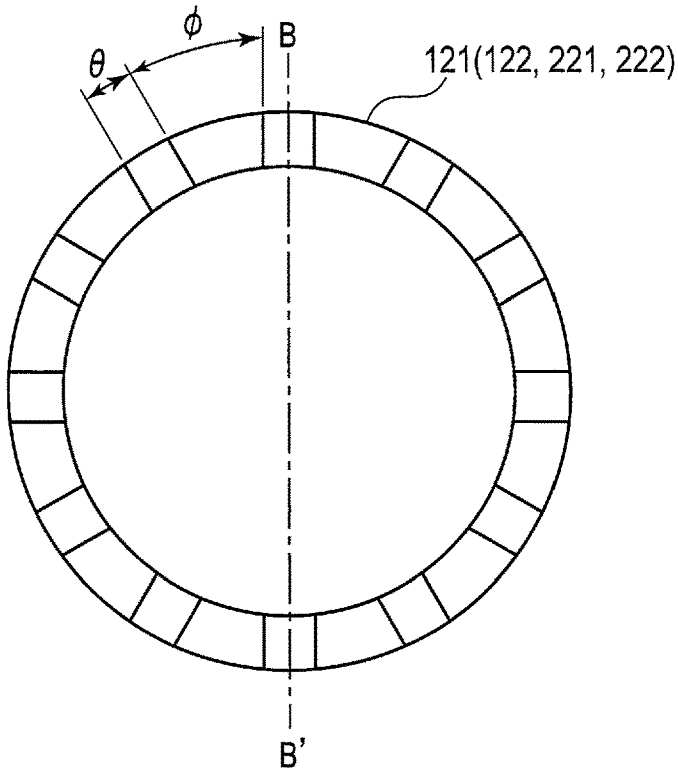
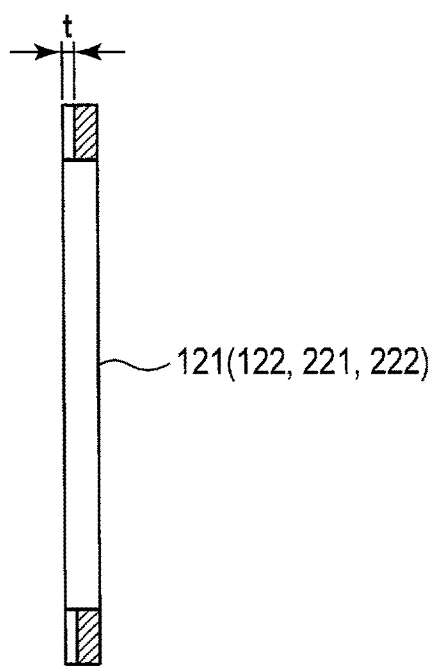

100
90
80
70
60
50
40
30
20
Sound Pressure Level [dB]
500
1000
1500
2000
Frequency [Hz]
(a)Without resonant cavity @reference voltage
(b)With resonant cavity @reference voltage
(c)With resonant cavity @reference voltage × 2
(d)With resonant cavity @reference voltage × 4

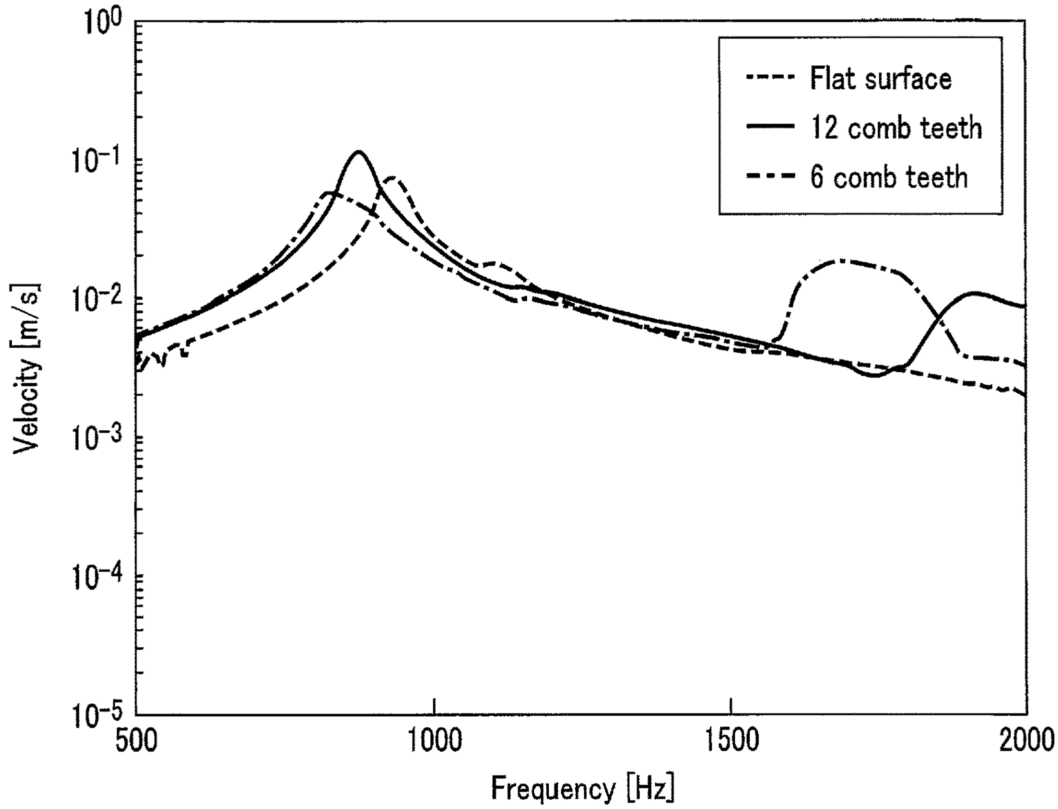
FIG. 24



F I G. 25A

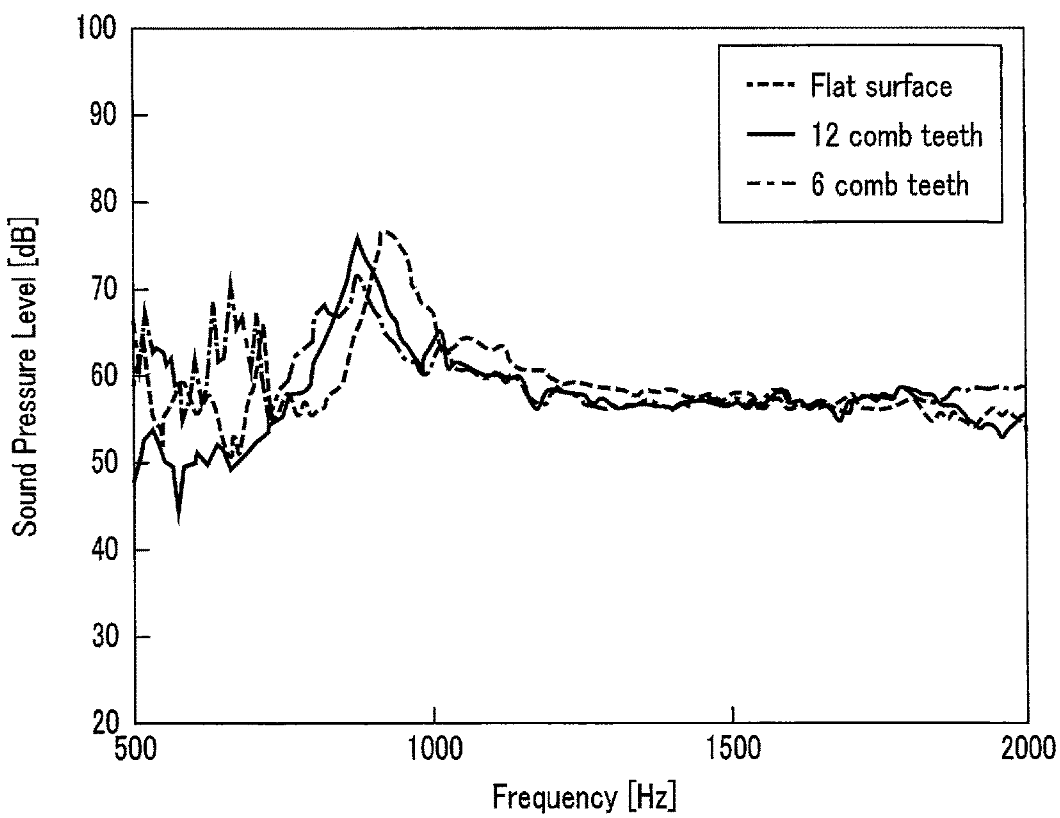


F I G. 25B



Flat surface
12 comb teeth
6 comb teeth
Velocity [m/s]
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
500
1000
1500
2000
Frequency [Hz]

FIG. 26



Flat surface
12 comb teeth
6 comb teeth
Sound Pressure Level [dB]
100
90
80
70
60
50
40
30
20
500
1000
1500
2000
Frequency [Hz]

FIG. 27

SOUND EMITTING APPARATUS

CROSS-REFERENCE TO RELATED APPLICATION

This application is based upon and claims the benefit of priority from prior Japanese Patent Application No. 2022-42834, filed Mar. 17, 2022, the entire contents of which are incorporated herein by reference.

FIELD

Embodiments described herein relate generally to a sound emitting apparatus.

BACKGROUND

In recent years, a sound source such as a noise control apparatus or a sound reproduction apparatus, which can generate high-output sound in a low frequency band is widely used. As the sound source, a dedicated speaker such as a woofer, which is good at reproducing low frequency sound, is normally used. However, the sound source good at reproducing low frequency sound is a bulky and heavy object in general, and it is intensively required to make it compact and lightweight from the viewpoint of extending the application range.

As a compact and lightweight sound source, a sound emitting apparatus (for example, a piezoelectric speaker or a piezoelectric buzzer) using a piezoelectric transducer has been developed mainly for portable electronic devices such as a portable telephone and a tablet terminal. However, normally, when the size and weight are reduced, the resonance frequency rises, and therefore, the apparatus is not suitable for low frequency sound reproduction.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a perspective view showing a sound emitting apparatus according to the first embodiment.

FIG. **2** is a front view showing the sound emitting apparatus according to the first embodiment.

FIG. **3** is a side view showing the sound emitting apparatus according to the first embodiment.

FIG. **4** is an exploded perspective view showing the sound emitting apparatus according to the first embodiment.

FIG. **5**A is a front view showing a piezoelectric transducer that is an example of a vibrator according to the first embodiment.

FIG. **5**B is a side view showing the piezoelectric transducer that is an example of the vibrator according to the first embodiment.

FIG. **6** is a side view showing a state in which a load weight is attached to the vibrator according to the first embodiment.

FIG. **7** is a side view showing a state in which a load weight is attached to the vibrator according to the first embodiment.

FIG. **8** is a view for explaining the outline of a principle verification test for a method according to the first embodiment.

FIG. **9** is a graph showing the frequency characteristic of the axial vibration velocity of the vibrator according to the first embodiment.

FIG. **10** is a graph showing the frequency characteristic of the radiated sound pressure of the sound emitting apparatus according to the first embodiment.

FIG. **11** is a graph showing the frequency characteristic of the axial vibration velocity of the vibrator according to the first embodiment, to which a load weight is attached.

FIG. **12** is a graph showing the frequency characteristic of the radiated sound pressure of the sound emitting apparatus according to the first embodiment, in which a load weight is attached to the vibrator.

FIG. **13** is a front view showing a sound emitting apparatus according to the second embodiment.

FIG. **14** is a side view showing the sound emitting apparatus according to the second embodiment.

FIG. **15** is a sectional view showing the sound emitting apparatus according to the second embodiment.

FIG. **16** is an exploded perspective view showing the sound emitting apparatus according to the second embodiment.

FIG. **17** is a side view showing the sound emitting apparatus according to the second embodiment.

FIG. **18** is an exploded perspective view showing the sound emitting apparatus according to the second embodiment.

FIG. **19** is a side view showing the sound emitting apparatus according to the second embodiment.

FIG. **20** is an exploded perspective view showing the sound emitting apparatus according to the second embodiment.

FIG. **21** is a graph showing the frequency characteristic of the axial vibration velocity of a vibrator according to the second embodiment.

FIG. **22** is a graph showing the frequency characteristic of the radiated sound pressure of the sound emitting apparatus according to the second embodiment.

FIG. **23** is a view for explaining the outline of a principle verification test for a method according to the second embodiment.

FIG. **24** is a graph showing the frequency characteristic of the radiated sound pressure of the sound emitting apparatus according to the second embodiment.

FIG. **25**A is a front view showing a holding part according to the third embodiment.

FIG. **25**B is a sectional view showing a holding part according to the third embodiment.

FIG. **26** is a graph showing the frequency characteristic of the axial vibration velocity of a vibrator according to the third embodiment.

FIG. **27** is a graph showing the frequency characteristic of the radiated sound pressure of a sound emitting apparatus according to the third embodiment.

DETAILED DESCRIPTION

According to an embodiment, a sound emitting apparatus includes a vibrator, a holding part, and a fixing part. The holding part is configured to hold the vibrator. The fixing part is configured to fix the holding part. A stiffness of the fixing part is lower than a stiffness of the holding part.

According to an embodiment, there is provided a compact and lightweight sound emitting apparatus capable of generating high-output sound in a low frequency band.

Hereinafter, embodiments will be described with reference to the accompanying drawings. In some drawings, one or more components are not shown.

First Embodiment

FIGS. **1**, **2**, **3**, and **4** are a perspective view, a front view, a side view, and an exploded perspective view, respectively, schematically showing a sound emitting apparatus **10** according to the first embodiment. As shown in FIGS. **1**, **2**, **3**, and **4**, the sound emitting apparatus **10** includes a vibrator **11**, a holding part **12**, and a fixing part **13**.

The vibrator **11** is a compact and lightweight vibration device. The vibration device is configured to vibrate upon receiving an electrical signal (for example, a voltage signal) from an electrical circuit (not shown) and generate sound according to the vibration. As the vibrator **11**, for example, a piezoelectric transducer may be used.

FIGS. **5**A and **5**B schematically show a piezoelectric transducer **50** that is an example of a piezoelectric transducer usable as the vibrator **11**. As shown in FIGS. **5**A and **5**B, the piezoelectric transducer **50** is a bimorph type piezoelectric transducer with piezoelectric elements **51** adhered to both surfaces of a circular metal plate **52**. A unimorph type piezoelectric transducer with a piezoelectric element adhered to one surface of a metal plate or a multilayered type piezoelectric vibrator formed by stacking piezoelectric elements may also be used.

Referring back to FIGS. **1**, **2**, **3**, and **4**, the holding part **12** holds the vibrator **11**. In the present embodiment, the holding part **12** is a two split type metal annular holder that holds the peripheral edge of the vibrator **11** by surface contact. Specifically, the holding part **12** includes a pair of holding members **121** and **122** each of which is made of a metal and has an annular shape. The holding members **121** and **122** sandwich the peripheral edge of the vibrator **11**, thereby holding the vibrator **11**.

Note that the holding part **12** shown in FIGS. **1**, **2**, **3**, and **4** is merely an example, and the configuration of the holding part **12** is not limited to the above-described configuration. For example, the holding part **12** may be a single holding member corresponding to the integration of the holding members **121** and **122**.

The fixing part **13** fixes the holding part **12**. In the present embodiment, the fixing part **13** is a two split type plastic annular holder that holds the holding part **12** by sandwiching both end faces of the holding part **12**. Specifically, the fixing part **13** includes a pair of fixing members **131** and **132** each of which is made of plastic and has an annular shape, stud bolts (threaded rods) **133**, and nuts **134**. Plastic is an example of an elastic material. The stiffness of the fixing part **13** (specifically, the fixing members **131** and **132**) is lower than the stiffness of the holding part **12**. The fixing members **131** and **132** are fastened by the nuts **134** and the stud bolts **133** arranged along the axial direction of the sound emitting apparatus (that is, in parallel to the Z-axis shown in FIGS. **2**, **3**, and **4**). Here, the axial direction of the sound emitting apparatus **10** is a direction orthogonal to the principal surface of the vibrator **11**. The fixing members **131** and **132** include through holes **135**. In a state in which the holding part **12** is placed between the fixing members **131** and **132**, the stud bolts **133** are inserted into the through holes **135** of the fixing members **131** and **132**, and the nuts **134** threadably engage with the stud bolts **133**. By the threaded engagement of the nuts **134**, a clamping force along the axial direction of the sound emitting apparatus **10** is generated, and the fixing part **13** supports the holding part **12** by the clamping force. Accordingly, the holding part **12** is elastically supported (flexibly supported) by the fixing part **13**, and the vibrator **11** is thus elastically supported.

Note that the fixing part **13** shown in FIGS. **1**, **2**, **3**, and **4** is merely an example, and the configuration of the fixing part **13** is not limited to the above-described configuration. For example, the fixing part **13** may have any configuration if it can elastically support the holding part **12**. Elastic support means a supporting method for permitting the displacement of the holding part **12** in the axial direction of the sound emitting apparatus **10**.

The shapes of the components shown in FIGS. **1**, **2**, **3**, and **4** are merely examples, and the shapes of the components are not limited to these. For example, the vibrator **11**, the holding part **12**, and the fixing part **13** may have a polygonal shape.

In the sound emitting apparatus **10**, as shown in FIG. **6**, a load weight **14** may be attached to the vibrator **11** to make the resonance frequency of the sound emitting apparatus **10** transition to a low frequency band. The load weight **14** is provided to add a mass to the vibrator **11**. For example, the load weight **14** includes a plastic bolt **141**, and one or more plastic nuts **142** (in this example, two plastic nuts **142**). A through hole is provided at the center of the vibrator **11**. The plastic bolt **141** is inserted into the through hole of the vibrator **11**, and the plastic nuts **142** threadably engage with the plastic bolt **141**.

As shown in FIG. **7**, the load weight **14** may further include one or more metal nuts **143** (in this example, four metal nuts **143**) to increase the mass added to the vibrator **11**. The metal nuts **143** threadably engage with the plastic bolt **141** in the rear stage of the plastic nut **142**.

The load weight **14** shown in FIG. **6** or **7** is merely an example, and the configuration of the load weight **14** attached to the vibrator **11** is not limited to the configuration shown in FIG. **6** or **7**. For example, in the configuration shown in FIG. **6**, a metal bolt may be used in place of the plastic bolt **141**. Also, the load weight **14** may be not the combination of the bolt and nuts but an elastic member such as a rubber plate.

The outline of a principle verification test for a method (proposed method) according to the present embodiment will be described next with reference to FIG. **8**. In this test, a sweep signal (500 Hz≤f≤2 kHz) amplified by an amplifier (class D amplifier) was input to the sound emitting apparatus **10** to drive the sound emitting apparatus **10**. A vibration velocity in the axial direction at the vibration observation point located almost at the center of the vibrator **11**, and a radiated sound pressure at a sound pressure observation point apart from the surface of the vibrator **11** by a predetermined distance were measured. To measure the vibration velocity, an LDV (Laser Doppler Vibrometry) was used, and to measure the sound pressure, a microphone was used. As the vibrator **11**, a bimorph transducer including a metal plate (stainless steel) and piezoelectric elements (lead zirconate titanate (PZT)) provided on both surfaces of the metal plate was used. An outer diameter Ro of the vibrator **11** was 45 mm, and a through hole (inner diameter Ri: 3 mm) was provided at the center of the vibrator **11**. The through hole is used to attach the load weight **14** to the vibrator **11**. The primary resonance frequency of the vibrator **11** in free support was about 1.3 kHz. Free support means a supporting method for permitting translational displacement and rotational displacement of the vibrator **11**. As the holding part **12**, a two split type metal annular holder (aluminum alloy) was used. As the fixing part **13**, a two split type plastic annular holder (ABS: Acrylonitrile Butadiene Styrene) was used.

FIGS. **9** and **10** show the results of the principle verification test for the proposed method. Specifically, FIG. **9** shows the frequency characteristic of the axial vibration velocity of the vibrator **11** measured by the above-described method, and FIG. **10** shows the frequency characteristic of the radiated sound pressure measured by the above-described method. FIGS. **9** and **10** also show the results of a test concerning a sound emitting apparatus according to a comparative example. The sound emitting apparatus according to the comparative example is formed by removing the holding part **12** from the sound emitting apparatus **10** according to the present embodiment. That is, in the sound emitting apparatus according to the comparative example, the vibrator **11** is directly supported by the fixing part **13**, and the vibrator **11** is rigidly supported as compared to the proposed method.

As shown in FIGS. **9** and **10**, the resonance frequency of the sound emitting apparatus according to the comparative example almost equals the primary resonance frequency of the vibrator **11**, but the resonance frequency of the sound emitting apparatus **10** according to the present embodiment is about 1,000 Hz, which is lower than the primary resonance frequency of the vibrator **11**. It is therefore found that when the vibrator **11** is held via the holding part **12**, the resonance frequency can be made to transition to a low frequency band. Furthermore, the sound emitting apparatus **10** according to the present embodiment has a wide resonance peak and can reproduce low frequency sound in a wider band, as compared to the sound emitting apparatus according to the comparative example.

Also, a test for verifying the effect of mass addition to the vibrator **11** was conducted. Mass addition to the vibrator **11** was done by the method described with reference to FIGS. **6** and **7**, and the axial vibration velocity and the radiated sound pressure of the vibrator **11** were measured by the same method as described above.

FIG. **11** shows the frequency characteristic of the axial vibration velocity of the vibrator **11** measured by the above-described method, and FIG. **12** shows the frequency characteristic of the radiated sound pressure measured by the above-described method. Each of FIGS. **11** and **12** shows four results: (a) without load weight, (b) plastic bolt (PB)×1 & plastic nut (PN)×2, (c) plastic bolt×1 & plastic nut×2 & metal nut (MN)×2, and (d) plastic bolt×1 & plastic nut×2 & metal nut×4. As can be seen from FIGS. **11** and **12**, the resonance frequency of the sound emitting apparatus **10** transitions to a lower frequency band along with the increase of the mass added to the vibrator **11**.

As described above, the sound emitting apparatus includes the vibrator **11**, the holding part **12** that holds the vibrator **11**, and the fixing part **13** that fixes the holding part **12** to elastically support the holding part **12**. For example, when the stiffness of the fixing part **13** is lower than the stiffness of the holding part **12**, the fixing part **13** can elastically support the holding part **12**. In this configuration, the vibrator **11** is elastically supported via the holding part **12**. This makes the resonance frequency of the sound emitting apparatus **10** transition to the low frequency band. As a result, even the compact and lightweight apparatus can reproduce high-output low frequency sound.

To add a mass to the vibrator **11**, the sound emitting apparatus **10** may further include the load weight **14** attached to the vibrator **11**. In this configuration, the resonance frequency of the sound emitting apparatus **10** can be made to transition to a lower frequency band.

Second Embodiment

FIGS. **13**, **14**, **15**, and **16** are a front view, a side view, a sectional view, and an exploded perspective view, respectively, schematically showing a sound emitting apparatus **20** according to the second embodiment. FIG. **15** shows a cross section of the sound emitting apparatus **20** taken along a line A-A' in FIG. **13**. As shown in FIGS. **13**, **14**, **15**, and **16**, the sound emitting apparatus **20** includes a vibrator **21**, a holding part **22**, a supporting part **23**, and a fixing part **24**.

The vibrator **21** is the same as the vibrator **11** of the sound emitting apparatus **10** according to the first embodiment. Hence, a description of the vibrator **21** will be omitted.

The holding part **22** is the same as the holding part **12** of the sound emitting apparatus **10** according to the first embodiment. Specifically, the holding part **22** includes a pair of holding members **221** and **222** each of which holds the peripheral edge of the vibrator **21** by surface contact. Each of the holding members **221** and **222** includes a plurality of threaded through holes **223**. The threaded through holes **223** extend along the radial direction of the sound emitting apparatus **20**. In each of the holding members **221** and **222**, the threaded through holes **223** are provided discretely in the circumferential direction of the sound emitting apparatus **20**. In the example shown in FIGS. **13**, **14**, **15**, and **16**, in each of the holding members **221** and **222**, eight threaded through holes **223** are provided at an angular interval of 45°.

The supporting part **23** supports the holding part **22**, and the fixing part **24** fixes the supporting part **23**. The stiffness of the supporting part **23** is lower than the stiffness of the holding part **22**. In the present embodiment, the supporting part **23** includes a plurality of metal bolts **231** each serving as an elastic member. The fixing part **24** is a two split type metal annular holder including a plurality of threaded through holes. The fixing part **24** includes a pair of fixing members **241** and **242** each of which is made of a metal and has an annular shape, and a plurality of metal bolts **243**. Each of the fixing members **241** and **242** is provided with a plurality of threaded through holes **244** and a plurality of threaded through holes **245**. A metal is an example of an elastic material. The threaded through holes **244** extend along the axial direction (Z-axis) of the sound emitting apparatus **20**, and the metal bolts **243** threadably engage with the threaded through holes **244**. The fixing members **241** and **242** are fastened by the metal bolts **243**. The threaded through holes **245** extend along the radial direction of the sound emitting apparatus **20**, and the metal bolts **231** threadably engage with the threaded through holes **245**. In each of the fixing members **241** and **242**, the threaded through holes **245** are provided discretely in the circumferential direction. In the example shown in FIGS. **13**, **14**, **15**, and **16**, in each of the fixing members **241** and **242**, eight threaded through holes **245** are provided at an angular interval of 45°.

The inner diameter of the fixing members **241** and **242** is slightly larger than the outer diameter of the holding members **221** and **222**. In a state in which the threaded through holes **245** of the fixing member **241** face the threaded through holes **223** of the holding member **221**, the fixing member **241** is arranged outside the holding member **221**, and the metal bolts **231** threadably engage with the threaded through holes **245** of the fixing member **241** and the threaded through holes **223** of the holding member **221**. In a state in which the threaded through holes **245** of the fixing member **242** face the threaded through holes **223** of the holding member **222**, the fixing member **242** is arranged outside the holding member **222**, and the metal bolts **231** threadably engage with the threaded through holes **245** of the fixing member **242** and the threaded through holes **223** of the holding member **222**. The metal bolts **231** are arranged discretely along the outer periphery of the holding part **22**. In the example shown in FIGS. **13**, **14**, **15**, and **16**, eight metal bolts **231** are arranged at an angular interval of 45° outside the holding member **221**, and eight metal bolts **231** are arranged at an angular interval of 45° outside the holding member **222**. When the metal bolts **231** are connected to the outer periphery of the holding part **22**, beam-style elastic support can be achieved.

Note that the supporting part **23** shown in FIGS. **13**, **14**, **15**, and **16** is merely an example, and the configuration of the supporting part **23** is not limited to the above-described configuration. The supporting part **23** may be formed by a plurality of plastic bolts or a film-shaped elastic member (for example, a rubber sheet). If the supporting part **23** is a rubber sheet, the supporting part **23** is arranged between the holding part **22** and the fixing part **24**.

The shapes of the components shown in FIGS. **13**, **14**, **15**, and **16** are merely examples, and are not limited to these. For example, the vibrator **21**, the holding part **22**, and the fixing part **24** may have a polygonal shape.

Furthermore, a load weight may be attached to the vibrator **21** to make the resonance frequency of the sound emitting apparatus **20** transition to a lower frequency band.

As shown in FIGS. **17** and **18**, the sound emitting apparatus **20** may further include an installation part **25** configured to install the sound emitting apparatus **20** in an arbitrary structure (for example, a resonant cavity). In the example shown in FIGS. **17** and **18**, the installation part includes a base member **251** and frame members **252** and **253**. The base member **251** includes a through hole **254** at the center, and a plurality of through holes **255** around the through hole **254**. The diameter of the through hole **254** is slightly larger than the outer diameter of the holding part **22**. The base member **251** is arranged between the fixing members **241** and **242** of the fixing part **24** and attached to the fixing part **24**. In a state in which the base member **251** is attached to the fixing part **24**, the vibrator **21** is located in the through hole **254**. The metal bolts **243** are inserted into the through holes **255**. The base member **251** is made of, for example, an elastic material. As the base member **251**, for example, a rubber sheet can be used. The stiffness of the installation part **25** (specifically, the base member **251**) is lower than the stiffness of the fixing part **24** (specifically, the fixing members **241** and **242**).

Each of the frame members **252** and **253** includes a through hole **256** at the center. The diameter of the through hole **256** is slightly larger than the outer diameter of the fixing members **241** and **242**. The base member **251** is arranged between the frame members **252** and **253** and attached to the frame members **252** and **253** using, for example, a combination of bolts and nuts. In a state in which the base member **251** is attached to the frame members **252** and **253**, the holding member **221** and the fixing member **241** are located in the through hole **256** of the frame member **252**, and the holding member **222** and the fixing member **242** are located in the through hole **256** of the frame member **253**. The frame members **252** and **253** correspond to frame bodies attachable to a structure. As the frame members **252** and **253**, for example, metal frame bodies can be used.

To increase the radiation sound pressure at the resonance frequency of the sound emitting apparatus **20**, the sound emitting apparatus **20** may further include a resonant cavity **26** having a resonance frequency substantially equal to the natural frequency of the vibrator **21**, as shown in FIGS. **19** and **20**. That the resonance frequency of the resonant cavity **26** substantially equals the natural frequency of the vibrator **21** means that the resonance frequency of the resonant cavity **26** falls within the frequency range of 200 Hz with respect to the natural frequency of the vibrator **21** as the center. If the natural frequency of the vibrator **21** is f Hz, the resonance frequency of the resonant cavity **26** is set within the frequency range from (f−100) Hz to (f+100) Hz.

Note that the configuration of the installation part **25** is not limited to the above-described configuration. For example, the base member **251** may be omitted, and the fixing part **24** (more specifically, the fixing members **241** and **242**) may be attached to the frame members **252** and **253**.

The vibrator **21**, the holding part **22**, the supporting part **23**, and the fixing part **24** are arranged in the resonant cavity **26** and attached to the resonant cavity **26** via the installation part **25**. The resonant cavity **26** includes case bodies **261** and **262**, and a plate **263**. The case bodies **261** and **262** form an internal space in which the vibrator **21**, the holding part **22**, the supporting part **23**, and the fixing part **24** are arranged. The case bodies **261** and **262** are fastened by, for example, bolts. An opening **264** that makes the internal space and the external space communicate is provided in the case body **262**, and the plate **263** is attached to the opening **264** of the case body **262**. The plate **263** includes a sound radiation aperture **265** configured to radiate sound generated by the vibrator **21** to the external space. The shapes of the case bodies **261** and **262** and the plate **263** are designed such that the resonance frequency of the resonant cavity **26** substantially equals the natural frequency of the vibrator **21**.

The installation part **25** and/or the resonant cavity **26** may also be applied to the sound emitting apparatus **10** according to the first embodiment.

A test for verifying the effectiveness of the configuration of the sound emitting apparatus **20** shown in FIGS. **17** and **18** was conducted. In the test, the axial vibration velocity of the vibrator **21** and the radiated sound pressure from the vibrator **21** were measured by the same method as described in the first embodiment. As the vibrator **21**, a bimorph transducer including a metal plate (stainless steel) and piezoelectric elements (lead zirconate titanate (PZT)) provided on both surfaces of the metal plate was used. An outer diameter Ro of the vibrator **21** was 45 mm. A through hole (inner diameter Ri: 3 mm) was provided at the center of the vibrator **21**. As the holding part **22**, a two split type metal annular holder (aluminum alloy) was used. As the supporting part **23**, a bolt (stainless steel) was used. As the fixing part **24**, a two split type metal annular holder (aluminum alloy) was used. As the installation part **25**, a rubber sheet (silicone, hardness: Shore A50) and a metal frame body (aluminum alloy) were used. Also, a load weight was attached to the vibrator **21** by the same method as described in the first embodiment. That is, a plastic bolt was inserted into a through hole provided at the center of the vibrator **21**, and a plastic nut was threadably engaged with the plastic bolt, thereby attaching the load weight to the vibrator **21**. To increase the mass added to the vibrator **21**, a metal nut was added to the rear stage of the plastic nut.

FIG. **21** shows the frequency characteristic of the axial vibration velocity of the vibrator **21** measured by the above-described method, and FIG. **22** shows the frequency characteristic of the radiated sound pressure measured by the above-described method. Each of FIGS. **21** and **22** shows four results: (a) without load weight, (b) plastic bolt×1 & plastic nut×2, (c) plastic bolt×1 & plastic nut×2 & metal nut×2, and (d) plastic bolt×1 & plastic nut×2 & metal nut×4. As shown in FIGS. **21** and **22**, the resonance frequency of the sound emitting apparatus **20** is lower than the primary resonance frequency of the vibrator **21**. Hence, according to the above-described configuration of the sound emitting apparatus **20**, the resonance frequency can be made to transition to a low frequency band. As can be seen from FIGS. **21** and **22**, the resonance frequency of the sound emitting apparatus **20** transitions to the low frequency band along with the increase of the mass added to the vibrator **21**.

However, the radiation sound pressure decreases along with the increase of the mass added to the vibrator **21**.

Next, a test for verifying the effectiveness of the resonant cavity **26** was conducted. The test was conducted by a method shown in FIG. **23**. Specifically, a radiation sound pressure at a sound pressure observation point apart from the sound radiation aperture **265** of the resonant cavity **26** by a predetermined distance was measured by a microphone. In addition, a load weight (plastic bolt×1 & plastic nut×2 & metal nut×4) was attached to the vibrator **21**.

FIG. **24** shows the frequency characteristic of the radiation sound pressure measured by the above-described method. FIG. **24** shows four results: (a) without resonant cavity, reference voltage is applied, (b) with resonant cavity, reference voltage is applied, (c) with resonant cavity, voltage twice larger than reference voltage is applied, and (d) with resonant cavity, voltage four times larger than reference voltage is applied. As can be seen from FIG. **24**, when the resonant cavity **26** is provided, the radiation sound pressure at the resonance frequency of the sound emitting apparatus **20** increases. It is also found that the radiation sound pressure linearly increases with respect to the voltage applied to the vibrator **21**.

As described above, the sound emitting apparatus includes the vibrator **21**, the holding part **22** that holds the vibrator **21**, the supporting part **23** that holds the holding part **22**, and the fixing part **24** that fixes the supporting part **23**. For example, when the stiffness of the supporting part **23** is lower than the stiffness of the holding part **22**, the supporting part **23** can elastically support the holding part **22**. In this configuration, the vibrator **21** is elastically supported via the holding part **22**. This makes the resonance frequency of the sound emitting apparatus **20** transition to the low frequency band. As a result, even the compact and lightweight apparatus can reproduce high-output low frequency sound.

The supporting part **23** and the fixing part **24** are arranged outside the holding part **22**. For example, the supporting part **23** may be formed by elastic members (for example, metal bolts) arranged discretely along the outer periphery of the holding part **22**. This can make the apparatus thin. Specifically, the size of the sound emitting apparatus **20** in the axial direction can be reduced.

The sound emitting apparatus **20** may further include the installation part **25**. This makes it easy to attach the sound emitting apparatus **20** to a structure.

The sound emitting apparatus **20** may further include the resonant cavity **26** having a resonance frequency that is substantially equal to the natural frequency of the vibrator **21**. This makes it possible to output sound at the resonance frequency of the sound emitting apparatus **20** in higher output.

To add a mass to the vibrator **21**, the sound emitting apparatus **20** may further include a load weight attached to the vibrator **21**. In this configuration, the resonance frequency of the sound emitting apparatus **20** can be made to transition to a lower frequency band.

Third Embodiment

In the first and second embodiments, the holding part that holds the vibrator is elastically supported, thereby making the resonance frequency of the sound emitting apparatus transition to the low frequency band. The resonance frequency of the sound emitting apparatus can also be made to transition to the low frequency band by a method to be described below. The method to be described in the third embodiment may be used solely, or may be combined with the method described in the first embodiment and/or the second embodiment.

It is known that the joint state between two objects affects the stiffness of a system. This stiffness is called a contact stiffness, and the material, surface roughness, contact area, and the like of the joint surface contribute to the contact stiffness. In the sound emitting apparatus (for example, a sound emitting apparatus **10** or a sound emitting apparatus **20**) according to the embodiment, the contact stiffness between the vibrator and the holding part affects the natural frequency of the vibrator. Hence, when the contact stiffness between the vibrator and the holding part is adjusted (specifically, lowered), the resonance frequency of the sound emitting apparatus can be made to transition to the low frequency band.

As methods of adjusting the contact stiffness, for example, the following three methods may be used.

(1) The material of the holding part is changed.
(2) The surface roughness of the holding part is changed.
(3) The contact area between the vibrator and the holding part is changed.

In the method (1), as the material of the holding part, a material (for example, an elastic material such as plastic) whose stiffness is lower than the material of the vibrator is used. For example, if the vibrator is a bimorph type piezoelectric transducer as shown in FIG. **5**, the holding part holds a metal plate. The holding part is made of a material whose stiffness is lower than the stiffness of the material of the metal plate.

In the method (2), in the contact region between the vibrator and the holding part, the surface roughness of the holding part is made higher (larger) than the surface roughness of the vibrator. In other words, the surface roughness of the region of the holding part in contact with the vibrator is larger than the surface roughness of the region of the vibrator in contact with the holding part.

In the method (3), in the contact region between the vibrator and the holding part, the surface area of the holding part is made smaller than the surface area of the vibrator. In other words, the surface area of the region of the holding part in contact with the vibrator is smaller than the surface area of the region of the vibrator in contact with the holding part. As an example of the method of making the surface area of the holding part smaller than the surface area of the vibrator in the contact region between the vibrator and the holding part, as shown in FIGS. **25**A and **25**B, the surface of the holding part (for example, each of holding members **121** and **122** shown in FIG. **1** or each of holding members **221** and **222** shown in FIG. **16**) is formed into a comb-tooth shape. FIG. **25**B shows a cross section of the holding part taken along a line B-B' in FIG. **25**A. A plurality of (**12**, in this example) concave portions having a thickness t are provided on the surface of the holding part.

FIGS. **26** and **27** show the results of a test for verifying the effectiveness of the comb-tooth shaped surface of the holding part. For the test, a holding part **22** of the sound emitting apparatus **20** shown in FIGS. **13**, **14**, **15**, and **16**, which has a comb-tooth shaped surface, was used. FIG. **26** shows the frequency characteristic of the axial vibration velocity of a vibrator **21**, and FIG. **27** shows the frequency characteristic of a radiated sound pressure from the sound emitting apparatus **20**. Each of FIGS. **26** and **27** shows three results: (a) flat surface, (b) 12 comb teeth (t: 1 mm, θ: 10°, ϕ:20°), and (c) 6 comb teeth (t: 1 mm, θ: 50°, ϕ: 20°). As can be seen from FIGS. **26** and **27**, the resonance frequency of the sound emitting apparatus transitions to a low frequency band when the holding part is formed into a comb-tooth shape. However, the surface shape shown in FIGS. **25**A and **25**B is merely an example, and the method of making the surface area of the holding part smaller than the surface area of the vibrator in the contact region between the vibrator and the holding part is not limited to this.

While certain embodiments have been described, these embodiments have been presented by way of example only, and are not intended to limit the scope of the inventions. Indeed, the novel embodiments described herein may be embodied in a variety of other forms; furthermore, various omissions, substitutions and changes in the form of the embodiments described herein may be made without departing from the spirit of the inventions. The accompanying claims and their equivalents are intended to cover such forms or modifications as would fall within the scope and spirit of the inventions.

What is claimed is:

1. A sound emitting apparatus comprising:
a vibrator comprising a metal plate and a piezoelectric element, the vibrator having a principal surface;
a holding part configured to hold the vibrator; and
a fixing part configured to fix the holding part,
wherein a stiffness of the fixing part is lower than a stiffness of the holding part,
the holding part includes an annular first holding member and an annular second holding member,
the first holding member and the second holding member sandwich a peripheral edge of the vibrator,
the fixing part includes an annular first fixing member provided with a plurality of through holes, an annular second fixing member provided with a plurality of through holes, a plurality of bolts, and a plurality of nuts,
the first fixing member and the second fixing member sandwich both end faces of the holding part, and
the bolts are arranged along an axial direction perpendicular to the principal surface of the vibrator, are inserted into the through holes of the first fixing member and the through holes of the second fixing member, and fasten the first fixing member and the second fixing member by a threaded engagement of the nuts with the holts.

2. The apparatus according to claim **1**, wherein the vibrator is a piezoelectric transducer.

3. The apparatus according to claim **1**, wherein the holding part holds a peripheral edge of the vibrator by surface contact.

4. The apparatus according to claim **1**, wherein the holding part is made of a material having a stiffness lower than a stiffness of a material of the metal plate.

5. The apparatus according to claim **1**, wherein a surface roughness of a region of the holding part in contact with the vibrator is higher than a surface roughness of a region of the vibrator in contact with the holding part.

6. The apparatus according to claim **1**, wherein a surface area of a region of the holding part in contact with the vibrator is smaller than a surface area of a region of the vibrator in contact with the holding part.

7. A sound emitting apparatus comprising:
a vibrator comprising a metal plate and a piezoelectric element;
a holding part configured to hold the vibrator;
a supporting part configured to support the holding part; and
a fixing part configured to fix the supporting part, wherein
the holding part includes an annular first holding member and an annular second holding member,
the first holding member and the second holding member sandwich a peripheral edge of the vibrator,
the fixing part has an annular shape, an inner diameter of the fixing part is larger than an outer diameter of the first holding member and an outer diameter of the second holding member, the fixing part is arranged outside the first holding member and the second holding member, and
the supporting part is connected to an outer periphery of the holding part.

8. The apparatus according to claim **7**, wherein a stiffness of the supporting part is lower than a stiffness of the holding part.

9. The apparatus according to claim **7**, further comprising an installation part configured to install the sound emitting apparatus in a structure,
wherein the installation part is attached to the fixing part.

10. The apparatus according to claim **9**, wherein a stiffness of the installation part is lower than a stiffness of the fixing part.

11. The apparatus according to claim **7**, further comprising a resonant cavity having a resonance frequency substantially equal to a natural frequency of the vibrator.

12. The apparatus according to claim **7**, wherein the vibrator is a piezoelectric transducer.

13. The apparatus according to claim **7**, wherein the holding part is made of a material having a stiffness lower than a stiffness of a material of the metal plate.

14. The apparatus according to claim **7**, wherein a surface roughness of a region of the holding part in contact with the vibrator is higher than a surface roughness of a region of the vibrator in contact with the holding part.

15. The apparatus according to claim **7**, wherein a surface area of a region of the holding part in contact with the vibrator is smaller than a surface area of a region of the vibrator in contact with the holding part.

16. The apparatus according to claim **7**, wherein the supporting part comprises a plurality of bolts,
the fixing part comprises a plurality of threaded through holes extending along a radial direction, and
the bolts are threadably engage with the threaded through holes.

17. The apparatus according to claim **7**, wherein the supporting part includes an elastic member arranged between the holding part and the fixing part.

18. The apparatus according to claim **7**, wherein
the vibrator has a principal surface, and
the fixing part comprises:
an annular first fixing member whose inner diameter is larger than the outer diameter of the first holding member, the first fixing member being arranged outside the first holding member, the first fixing member being provided with a plurality of first threaded through holes extending along a direction perpendicular to the principal surface,
an annular second fixing member whose inner diameter is larger than the outer diameter of the second holding member, the second fixing member being arranged outside the second holding member, the second fixing member being provided with a plurality of first threaded through holes extending along the direction perpendicular to the principal surface, and
a plurality of first bolts configured to fasten the first fixing member and the second fixing member via the

first threaded through holes of the first fixing member and the first threaded through holes of the second fixing member.

19. The apparatus according to claim 18, wherein

the supporting part comprises a plurality of second bolts and a plurality of third bolts,

the first fixing member is provided with a plurality of second threaded through holes extending along a radial direction,

the second fixing part is provided with a plurality of second threaded through holes extending along a radial direction,

the second bolts threadably engage with the second threaded through holes of the first fixing member, and

the third bolts threadably engage with the second threaded through holes of the second fixing member.

20. The apparatus according to claim 7, wherein the holding part is a single member in which the first holding member and the second holding member are integrally formed.

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